Intercomparison of MODIS - Aqua C051 and C006 Level 3 Deep Blue AOD and Ångström exponent retrievals over the Sahara desert and the Arabian Peninsula during the period 2002 - 2014

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European Geosciences Union
General Assembly 2015
Vienna | Austria | 12 - 17 April 2015

Introduction

Dust loads emitted from the arid regions of Northern Africa and Arabian Peninsula account for the major portion of the global dust aerosol burden. These areas, based on satellite observations, host the major dust sources of the planet (Prospero et al., 2002; Washington et al., 2003; Ginoux et al., 2012) located in Bodélé Depression, Mali and Mauritania, in Arabia and in Libya. Depending on the prevailing atmospheric circulation dust aerosols can be transported far away from their source areas. Nevertheless, the transport over the Atlantic Ocean is well confined in the Saharan Air Layer (SAL, Karyampudi et al., 1999) while over the Mediterranean has a multilayered structure (Hamonou et al., 1999). Given the adverse health effects (Karanasiou et al., 2012) and the key role of dust aerosols to weather and climate a better description of their spatial and temporal variability is of great importance. Such a complete spatio-temporal variability can only be ensured by satellite data.

Aim of the study

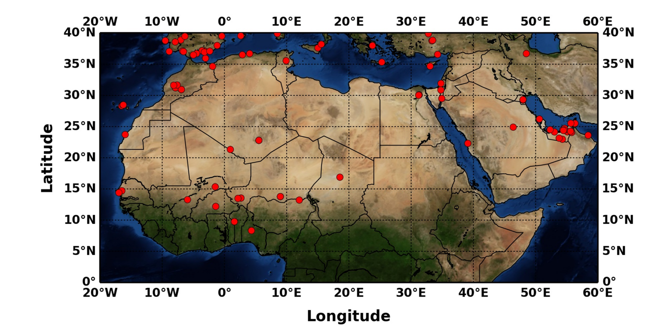
This study is focused on the comparison between the MODIS-Aqua Collections 051 (C051) and 006 (C006) aerosol optical depth at 550nm and Ångström exponent (412-470nm), which are both retrieved by the Deep Blue (DB) Algorithm (Hsu et al., 2004). Previous versions of MODIS data did not provide aerosol retrievals over the arid regions of the planet (e.g. deserts). This "gap" was filled by the DB algorithm which takes advantage of the low surface reflectance of deserts at the deep blue wavelength of 412nm. The first DB outputs were stored in C005, named as C051. Recently, the second generation (enhanced) of the DB algorithm is used in the latest version (C006) of the MODIS-Aqua dataset (Hsu et al., 2013). The updates in the enhanced DB algorithm concern the surface reflectance estimation, the aerosol model selection and the cloud screening schemes (Hsu et al., 2013). In the present analysis, the daily Level 3 C051 and C006 retrievals are compared both at pixel level (geographical distributions) and regional scales over the Sahara Desert and the Middle East during the 12-year period 2002-2014. Moreover, in order to assess the performance of the satellite retrievals, these optical properties are evaluated against the corresponding ones retrieved by 86 AERONET stations located within the study region.

Data

Study period: 4 July 2002 - 3 July 2014
Study region: 20° W to 60° E / 0° to 40° N
Satellite sensor: MODIS - Aqua
File names: MYD08_D3
Temporal resolution: Daily retrievals
Spatial resolution: 1° x 1° (Level 3)
Collections: Collection 051 (C051), Collection 006 (C006)

Scientific data sets (SDS's):
- Deep_Blue_Aerosol_Optical_Depth_550_Land_Mean
- Deep_Blue_Angstrom_Exponent_Land_Mean

Study region - AERONET stations

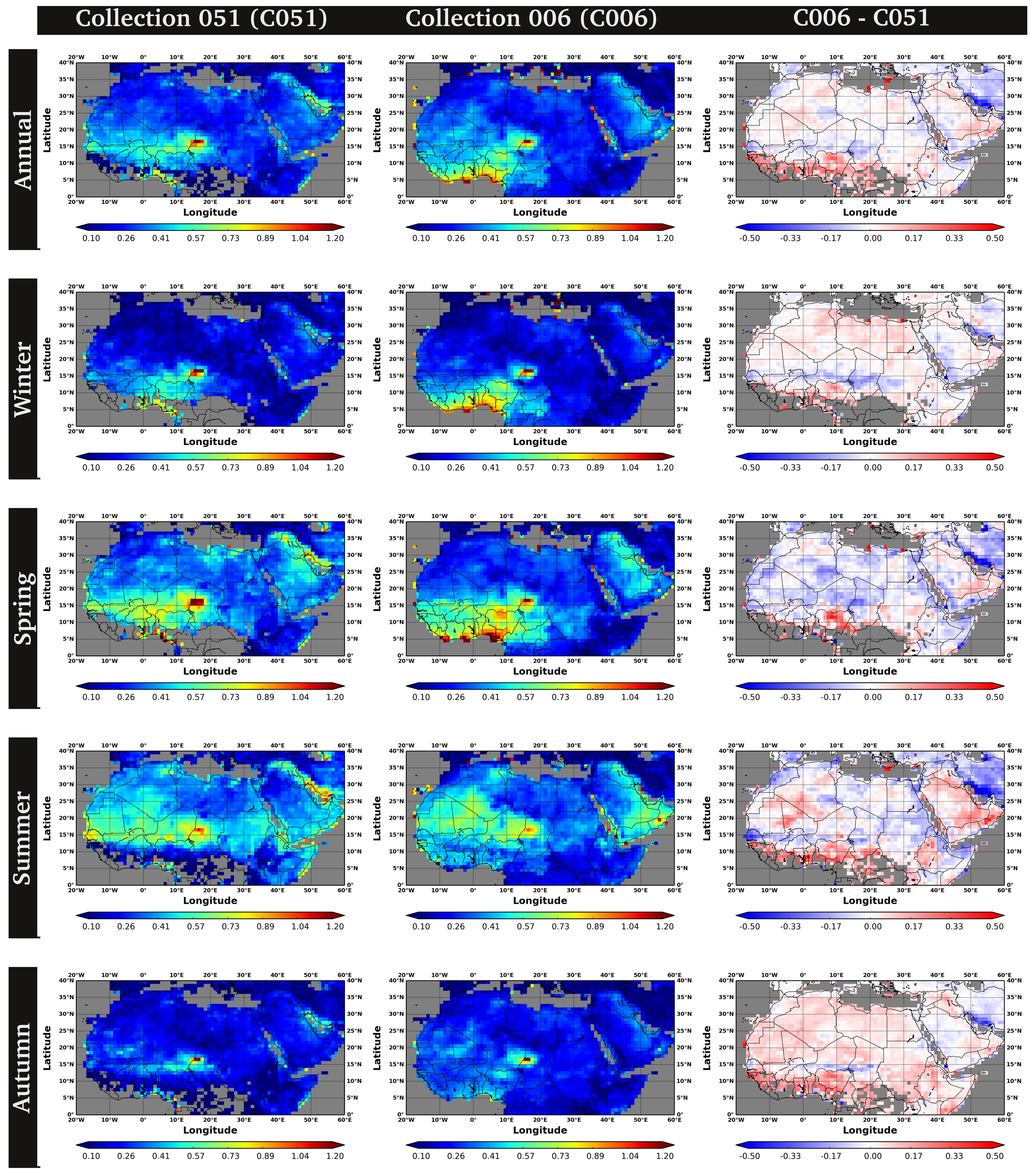


Results

Geographical distributions

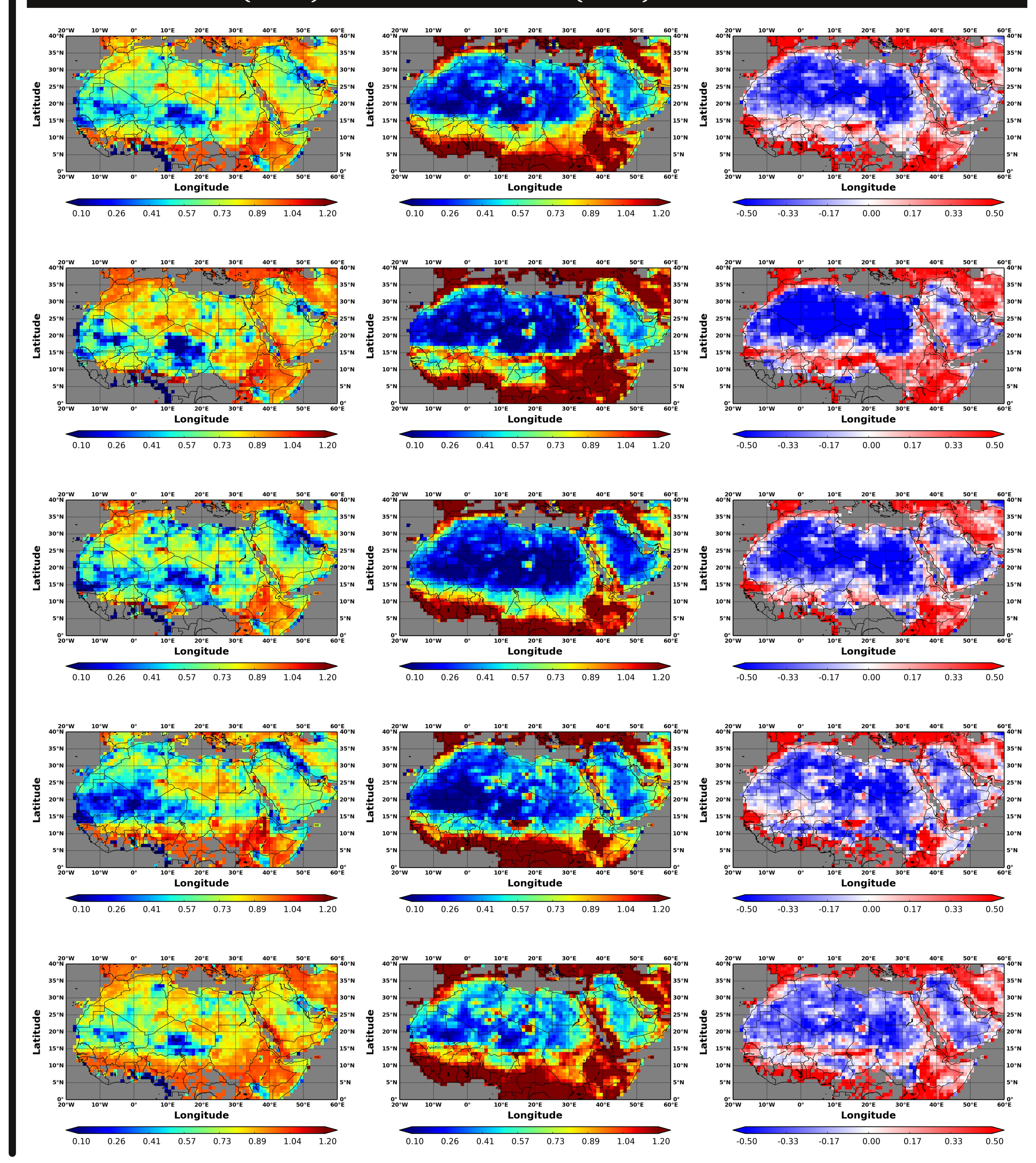
Aerosol optical depth at 550nm

Collection 051 (C051) | Collection 006 (C006) | C006 - C051



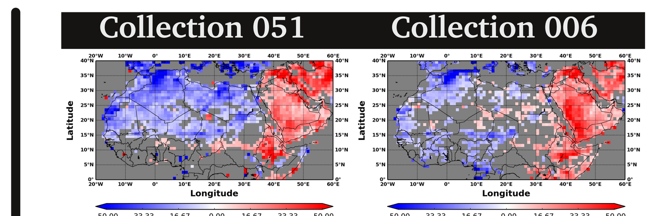
Ångström exponent (412 – 470nm)

Collection 051 (C051) | Collection 006 (C006) | C006 - C051



AOD trends (%)

Collection 051 | Collection 006



Aerosol optical depth
The obtained long-term geographical distributions reveal many similarities between C051 and C006 AODs. They both indicate a zone of high AODs along the parallel of 15°N, extending from the western coasts of Africa to Chad, where the maximum values (1.3) are recorded. In the Arabian Peninsula, the maximum AODs (up to 0.6) are found in Iraq. However, differences also appear between the two collections, e.g. larger C006 AOD values over the southernmost part of western Africa, from Liberia through Nigeria, whereas lower values appear around the Persian Gulf. Also, C006 AOD is retrieved in locations of central Africa where C051 was not available. In winter through spring, when noticeable differences exist between C051 and C006, high AODs are observed across the sub-sahel regions down to areas adjacent to the Gulf of Guinea, due to the biomass burning aerosols and the transport of Saharan dust particles favored by the prevailing Harmattan winds. In summer, AODs are increased over the western Sahara and the eastern Arabian Peninsula, as mainly indicated by C006 data. Throughout the year, C006 AODs are lower than C051 ones in regions where maximum AODs are recorded. Positive C006-C051 differences are found over the Sahara during winter and autumn and in summer over the Arabian Peninsula. Negative C006-C051 differences are found over Sahara in spring, sub-Sahel in winter and north of Persian Gulf throughout the year.

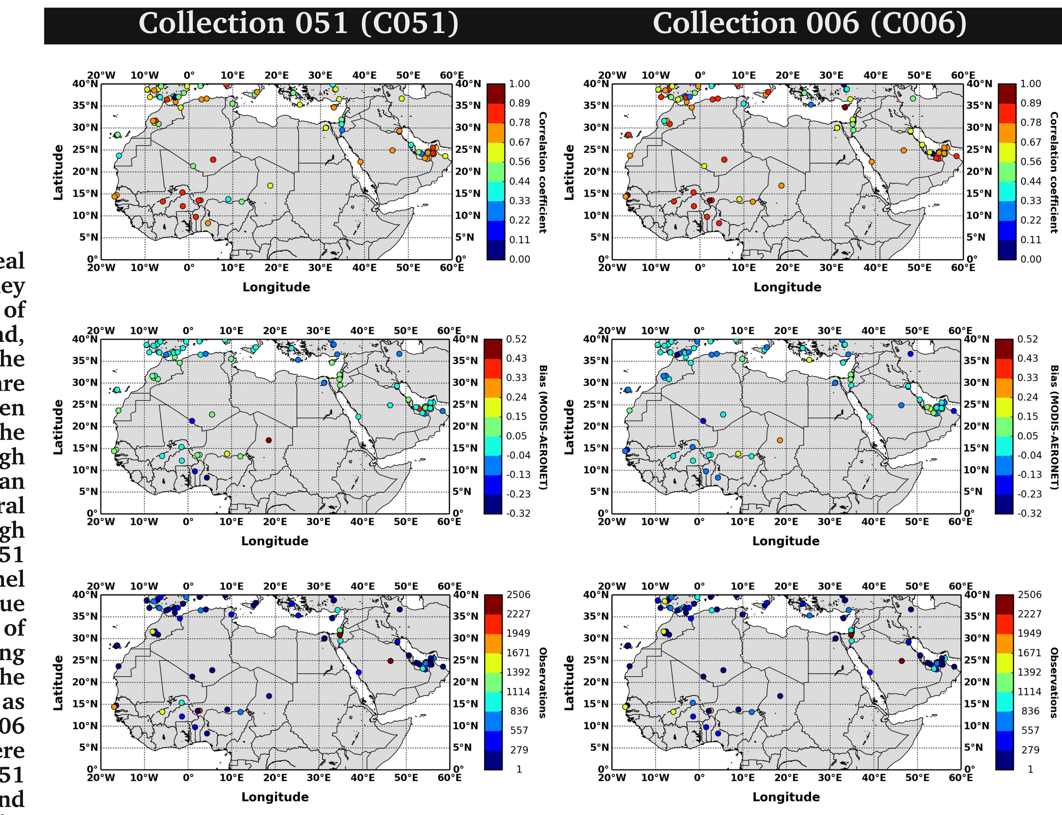
Ångström exponent
More apparent differences are found between the two collections for the alpha retrievals than AOD. It is evident a reduction of C006 values which is more pronounced over the desert areas of the study region. This is valid on an annual basis but also throughout the year. The decrease in C006 alpha, results in low values over the deserts of N. Africa and Middle East, varying from 0 to 0.6, while in C051 they reach values up to 1.0.

AOD trends (%)
Significant changes (95% confidence level) of AOD during the period 2002-2014 are indicated by both collections, ranging from 10% to 50%. Uniform negative tendencies are observed over Sahara against increasing tendencies over the Arabian Peninsula and Middle East. Positive trends over the Arabian Peninsula, have been also found by Hsu et al. (2012) based on SeaWIFS and AERONET data, for the period 1997-2010. Tendencies of such magnitude for AOD can be very important in radiative and climate terms for the study region.

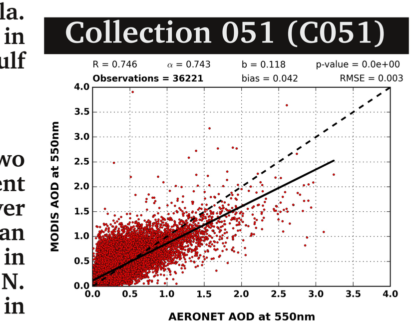
MODIS vs AERONET

Aerosol optical depth at 550nm

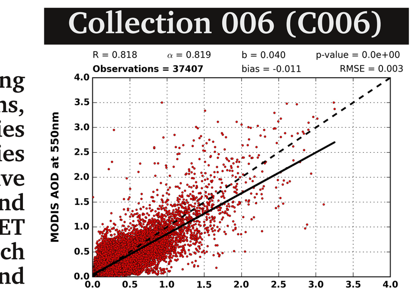
Collection 051 (C051) | Collection 006 (C006)



Collection 051 (C051)



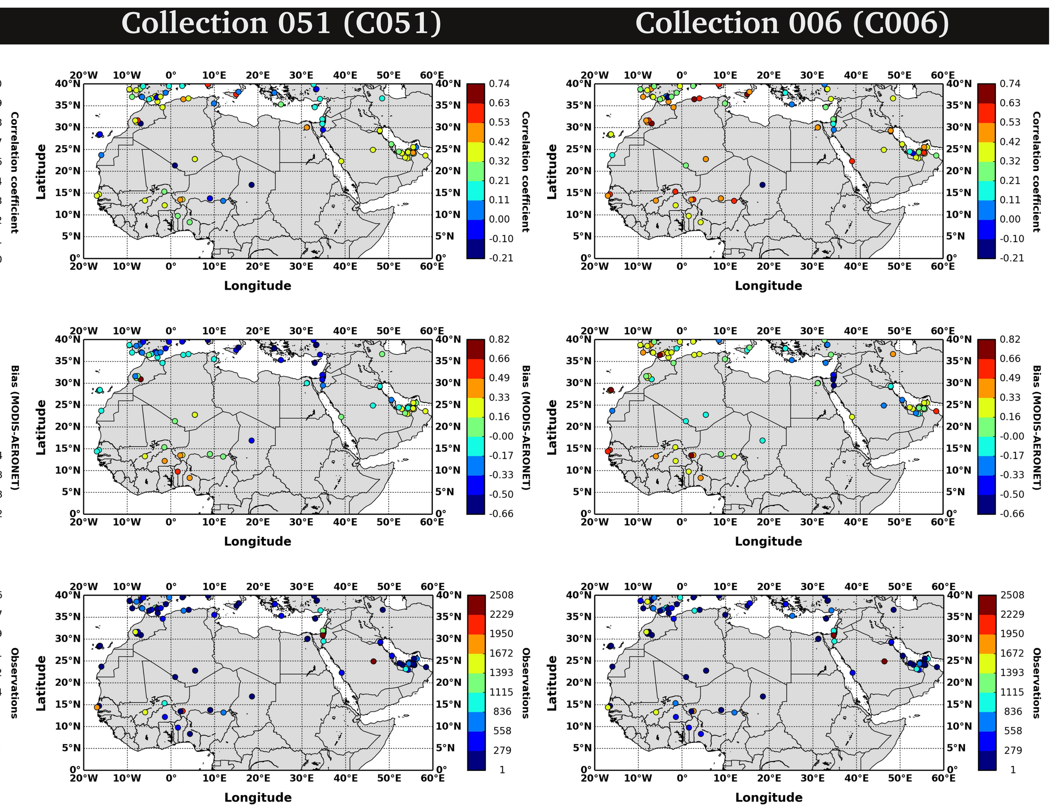
Collection 006 (C006)



For each of the 86 AERONET stations, the correlation coefficients (R), the biases as well as the number of common observations between satellite and ground AODs have been calculated, for both collections. In C051, R values in the majority of the stations are higher than 0.6 reaching up to 0.88 (Niamey). The average differences between MODIS and AERONET retrievals are negligible but exceptionally can be higher either positive (0.52) or negative (-0.32). For C006, R values increase in many stations. The best performance is found in AERONET sites located across the Western Sahara, in United Arab Emirates and Oman. Based on the overall scatterplots, there is a clear improvement of the covariation between ground and satellite measurements from C051 to C006. More specifically, the R values increase from 0.746 to 0.818. The better agreement of C006 than C051 with AERONET is also indicated by the decreasing magnitude of bias and the higher slope of linear fit. MODIS is underestimating at high AOD levels, while at low AOD conditions the C051 overestimates while C006 matches well AERONET. Our results are in line with those presented by Sayer et al. (2013) for the Collection 006.

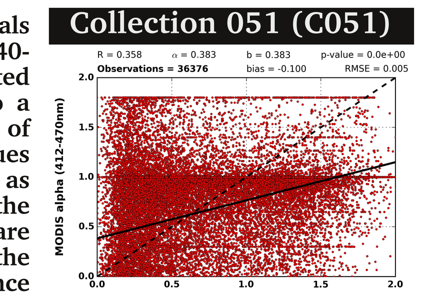
Ångström exponent (412 – 470nm)

Collection 051 (C051) | Collection 006 (C006)

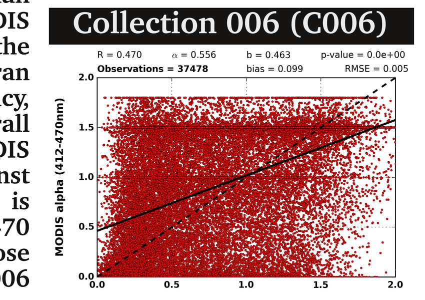


A similar analysis was made for the alpha retrievals provided by MODIS (412-470nm) and AERONET (440-870nm). It should be noted that due to limited sensitivity, in low AOD conditions alpha is set to a prescribed value dependent on surface type instead of being retrieved. Among the 86 stations, R values range from -0.21 to 0.74. In C051, R values can be as high as 0.53 in AERONET stations located near to the main dust sources. On the contrary, R values are increased in C006, varying from 0.42 to 0.63, in the central parts of the Sahara Desert. The performance of C006 is better in the Northern African deserts than in the Middle East. Across the Mediterranean, MODIS C051 alpha is underestimated by up to 0.33, while the C006 data are mainly overestimated. In the Saharan and Arabian stations there is not a uniform tendency, with either positive or negative biases. The overall scatterplots verify the poorer performance of MODIS C051 and C006 alpha than AOD retrievals against AERONET, although a noticeable improvement is found, with R increasing from 0.358 (C051) to 0.470 (C006). The findings are in agreement with those reported by Sayer et al. (2013) for the Collection 006 Level 2 (10km x 10km) retrievals.

Collection 051 (C051)

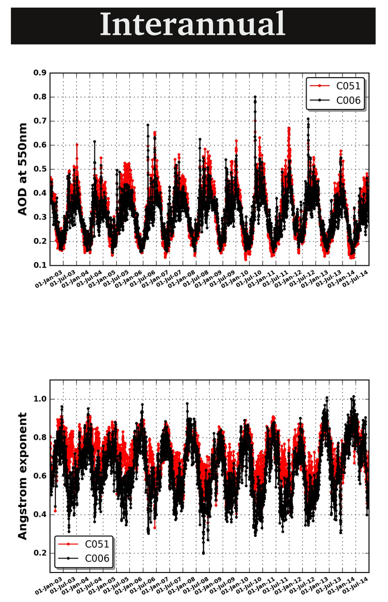


Collection 006 (C006)

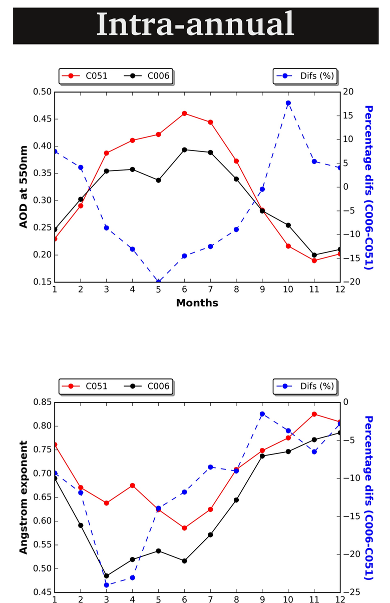


Regional analysis

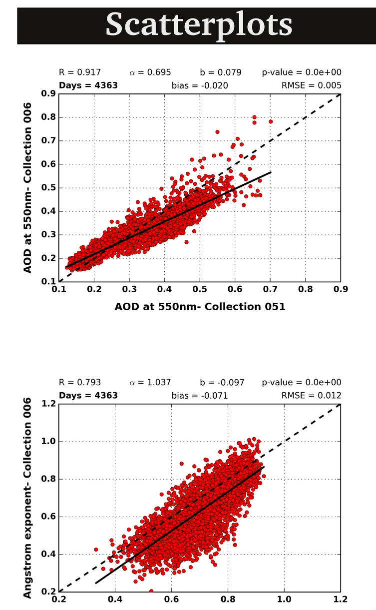
Interannual



Intra-annual



Scatterplots



On a mean regional basis, both collections suggest the existence of a seasonal AOD cycle, occurring year by year, with higher values during boreal spring and summer and lower values in autumn and winter. Nevertheless, in spring and summer the C006 AODs are lower than C051 ones by up to 20%, whereas they are higher in autumn by up to 15%. The monthly C051 AODs vary between 0.18 (November) and 0.47 (June). Although the seasonal cycle does not change in C006, there are two maxima, one in spring (0.35, April) and one in summer (0.38, June). Although there is a good correlation between the two collections (R=0.917), the comparison reveals an overestimation/underestimation of C006 with respect to C051 in lower/higher AODs than 0.25. The year by year alpha values range from 0.2 to 1, being rather higher in C051 than C006. This is verified in mean 2002-2014 seasonal plot, where alpha is lower in C006 than C051 throughout the year, more in spring and summer (by up to 25%). The scatterplot indicates that the correlation between C006 and C051 is not that good for alpha, with a correlation coefficient equal to 0.793. The C006 alpha retrievals are lower than the C051 ones since the majority of the common data pairs is below the equality line. Finally, the seasonal variations of the two optical properties (AOD and alpha) are found to be reverse; this is consistent with the dominant aerosol type being mineral dust.

Conclusions

Aerosol optical depth

Similar annual and seasonal spatial patterns are found between MODIS C051 and C006 AOD retrievals. The maximum AODs (up to 1.3) are recorded in the Bodélé Depression (Chad) while high AODs are also observed westwards, in western Sahara but also southwestwards down to the coast of the Guinea's Gulf. Over the Middle East, the highest AODs (up to 0.6) are found in Iraq and near the Persian Gulf. During winter and spring, high AODs are observed in the sub-Sahel areas attributed to the co-existence of the locally produced biomass burning aerosols and the transported Saharan dust particles by the prevailing Harmattan winds. In summer, it is evident a shift of high AOD values northwards, with increased AODs over the Western Sahara and the eastern parts of the Arabian Peninsula due to the enhanced dust storm activity. In general, C006 AODs retrievals are lower, by up to 0.5, than the C051 ones over the regions where the maximum aerosol optical depths are observed. Across the northern African deserts, positive C006-C051 differences are more frequent in winter and autumn while negative ones are recorded particularly in spring but also in summer. Over the Middle East, the positive C006-C051 differences are more pronounced in summer and less in autumn. Both C006 and C051 data indicate that the aerosol load over the Sahara has decreased by up to 50% from 2002 to 2014. On the contrary, increasing tendencies are determined over the Middle East and Arabian Peninsula. During the study period, the mean regional AODs range from 0.15 to 0.80 revealing a seasonal cycle with maximum values in summer and minimum ones in late autumn and early winter. During high dust seasons, C051 AODs are higher than C006 ones by up to 20%. According to the overall scatterplots, the good agreement of C051 AOD with AERONET is further improved for C006 (R, bias and slope and intercept values). Yet, the underestimation of MODIS AODs under high aerosol load conditions is smaller in C006 than C051.

Ångström exponent

In contrast to AOD, different spatial patterns are revealed between C051 and C006 alpha retrievals. The C006 alpha values are lower than 0.5 over the desert areas while in C051 they are higher reaching up to 1. This is valid on a both year and seasonal basis, with the C006 alpha values being lower than C051 ones throughout the year, by up to 25% (in spring). Though the correlation between C006 and AERONET alpha measurements is low (R=0.470), it has been improved compared to C051-AERONET (R=0.358).

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Acknowledgements

The MDRAF project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 622662

Spanish Ministry of Economy and Competitiveness through the project CGL2013-46736-R